LITHIUM CARBON MONOFLUORIDE: THE NEXT PRIMARY CHEMISTRY FOR SOLDIER PORTABLE POWER SOURCES

Arek Suszko
RDECOM, CERDEC, Army Power Division
Fort Monmouth, N.J. 07703

1. ABSTRACT

The US Army is interested in a low cost, high energy density primary lithium power source for use as the energy source for field charging units, for use in advanced man portable electronic equipment, and for unmanned and unattended systems. Lithium metal can provide a theoretical 13 Kilowatt-hours/kilogram based on the metal. This is ten times greater than the theoretical specific energy of zinc. It is imperative that the government invests in this chemistry and reduces the burden on the soldiers. Current lithium-ion rechargeable battery technologies have a specific energy of 170 Watt-hours/kilogram and state-of-the-art primary lithium-based systems have a specific energy approaching 200 Watt-hours/kilogram. A weight burden is added to the user as a result of this low specific energy and additional logistic support is required for recharging. It is imperative that the novel lithium power energy source have a superior specific energy (>400 Watt-hours/kilogram) and a moderate specific power (>50 Watts/kilogram).

2. INTRODUCTION

Lithium carbon monofluoride (Li/CF_x) is an attractive 3 V system because it has the highest theoretical energy density (~2180 Wh/kg) among the primary lithium systems. In addition, it has a flat discharge profile (2.5-2.7 V), a wide operating temperature range (-40^{o}C to 85^{o}C), low self discharge, and long shelf life (> 10 years). The CF_x cathode active material is inherently safe because it is stable and inert up to 400^{o}C. Currently, the two main obstacles to its implementation include low rate capability and heat generation accompanied with high rate discharge. In addition, the CF_x active material is currently only produced in limited quantities.

The active components in the cell include lithium as the anode and carbon monofluoride (CF_x) in the cathode. During discharge, the reaction products lithium fluoride (LiF) and amorphous carbon (C) form:

$$xLi + (CF)_x \rightarrow xLiF + xC \text{ (OCV = 3.2 V)}$$

Several companies are working with Li/CF_x and have produced viable cylindrically wound D-cells.

3. RESULTS & DISCUSSION

The Li/CF_x D-cells pictured in figure I were evaluated on ARBIN and MACCOR battery test systems. The open circuit voltages (OCV) for these prototype D-cells varied from 3.17 V to 3.53 V. Table I summarizes weight, OCV, and specific energy values. The specific energy of these D-cells is approximately 2 times that of what is currently available in the field today. Figure II shows a room temperature 2 A constant current discharge. Each of the D-cells has a smooth discharge profile and provides around 7 Ah of capacity at a 2 V cutoff. Figure III shows a comparison between lithium sulfur dioxide (Li/SO_2), lithium manganese dioxide (Li/MnO_2), and lithium carbon monofluoride (Li/CF_x). It can be seen that Li/CF_x has the highest capacity (Ah) that translates into the longest runtime. In addition, the Li/CF_x D-cell weighs less than the other two chemistries resulting in the highest

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specific energy (Wh/kg) and a reduced weight burden.

Over the last year there has been an improvement in the capacity of the Li/CF_x D-cell. The cells shown in figure IV were discharged at 1A and 2A to 2V. The resulting capacities were 16.6 Ah and 17.0 Ah, respectively. This is an improvement of nearly 2Ah from the previous design. The calculated energy density is 490 Wh/kg for this D-cell.

In addition to cell testing, the BA-X800 and the BA-XX47 battery pack configurations were compared. In figure V, the BA-XX47 battery pack having two D-cells in series was compared using Li/MnO_2 and Li/CF_x chemistries. The Li/CF_x version lasted an additional 1 ½ hours longer than Li/MnO_2. Its lower weight contributes to a higher energy density of 270 Wh/kg compared to Li/MnO_2 that has 185 Wh/kg. There is a greater disparity between the Li/MnO_2 BA-X800 and the Li/CF_x BA-X800 because a lower capacity Li/MnO_2 D-cell is used. The Li/CF_x BA-X800 ran an additional 3 hours when compared to the Li/MnO_2 BA-X800 version. The resulting energy densities are 380 Wh/kg for Li/CF_x and 170 Wh/kg for Li/MnO_2 in the BA-X800 battery configuration.

Figure I – Company A, B, and C lithium carbon monofluoride D-cells.

4. FUTURE WORK

There are two technical hurdles that remain for the lithium carbon monofluoride chemistry that are under investigation. The current prototype D-cells and battery packs exhibit a voltage delay at the onset of discharge. These can be seen in figures IV for the D-cell and figures V and VI for the battery packs. For the two battery pack configurations tested the voltage delay cannot exceed 5 seconds below 4V. In addition, there are thermal issues that will need to be addressed in the cell design and battery configuration. Figure VII shows a D-cell that shows a temperature of 64^{o}C at the end of discharge. Temperature plays a more significant role in a battery pack where the cells are in a plastic case. In the Li/CF_x BA-XX47 battery pack the resulting temperature was 74^{o}C.

Table I – Company A, B, and C lithium carbon monofluoride D-cells characteristics. Specific energies varied from 379 Wh/kg to 457 Wh/kg given a 2A constant current discharge to 1.5V.

Company Name	Company A	Company B	Company C
OCV (V)	3.35, 3.36	3.17, 3.53	3.28, 3.32
weight (g)	89.0	85.18, 85.74	74.34, 71.65
length (mm)	55.9	57.5	61.7
diameter (mm)	33.1	33.0	34.2
Specific Energy* (Wh/kg)	379	420	457**

*2A to 1.5V

** using Al can

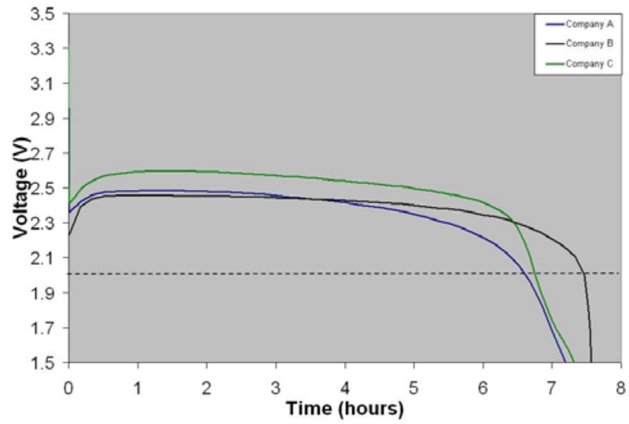

Figure II – Company A, B, and C lithium carbon monofluoride D-cells discharged at 2A to 1.5V at 25^{o}C.

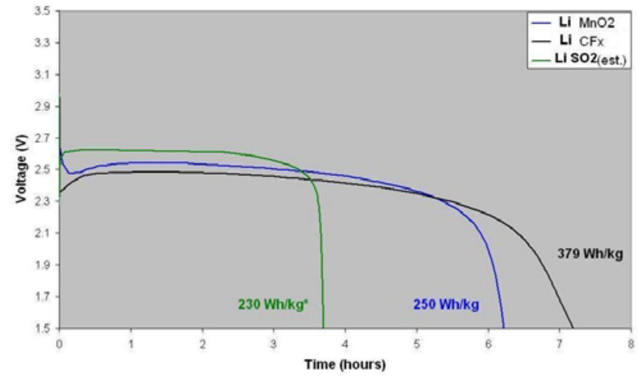

Figure III – Lithium sulfur dioxide (Li/SO_2), lithium manganese dioxide (Li/MnO_2), and lithium carbon monofluoride (Li/CF_x) D-cell discharge at 2A to 1.5V at 25^{o}C comparison.

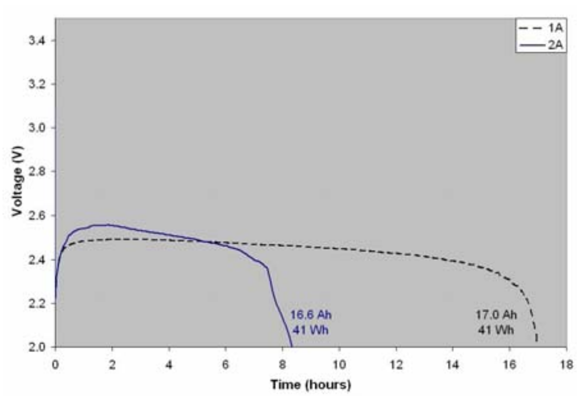

Figure IV – Improved Li/CF_x D-cell with higher capacity discharged at 1A and 2A to 2V at 25^{o}C.

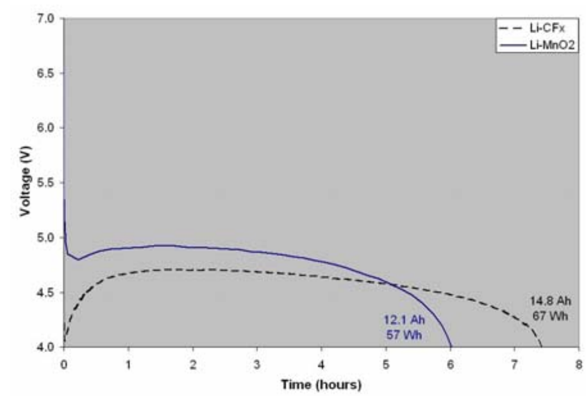

Figure V – BA-XX47 battery comparison between Li/MnO_2 and Li/CF_x discharged at 2A to 4V at 25^{o}C.

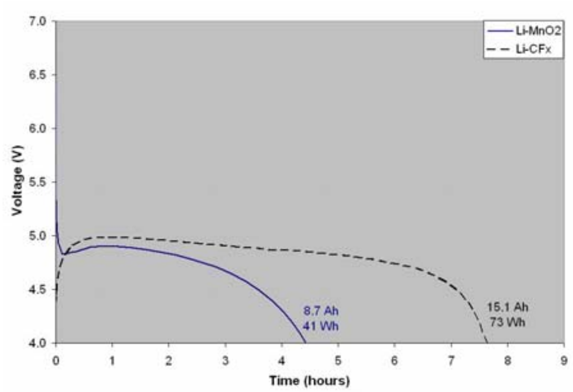

Figure VI – BA-X800 battery comparison between Li/MnO_2 and Li/CF_x discharged at 2A to 4V at 25^{o}C.

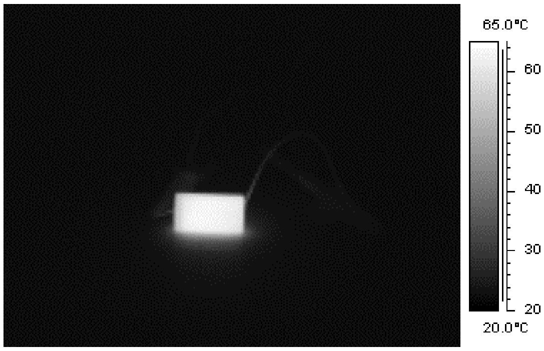

Figure VII – Thermal image of a Li/CF_x D-cell showing temperature of 64°C.

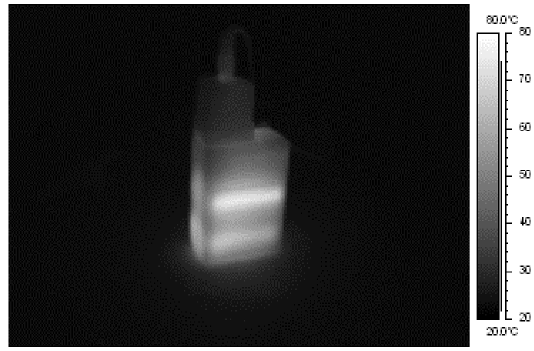

Figure VIII – Thermal image of a BA-XX47 battery with Li/CF_x D-cell showing temperature of 74°C.